Automated Roadway Debris Vacuum (ARDVAC)

Business Development Case

Draft Report

June 11, 2006

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Executive Summary

The Automated Roadway Debris Vacuum (ARDVAC) is a self-contained vacuum system that allows for easy removal of debris from roadway edges and collection of the litter that tends to blow up against fence lines, vegetation, guardrails and other objects. Using a joystick control from within a cab, an operator can quickly vacuum behind guard rails, down into depressions, and under bushes. The ARDVAC also increases safety by reducing worker exposure to traffic.

Objectives of this Study

- Identify and quantify benefits to Caltrans, Caltrans maintenance workers, and society.
- Identify customers beyond Caltrans.

Value Proposition

The ARDVAC will allow Caltrans to efficiently remove debris from locations where it is either unsafe or impossible to remove by hand. Using the ARDVAC in these conditions is more cost-effective than manual litter pick-up operations by Caltrans crews would be if they were allowed.

Value to Caltrans: Cost Savings / Cleaner Highways

- Cost savings is estimated at $122 per mile for ARDVAC with a fixed lane closure versus pick-up by a Caltrans crew. This value was identified as conservative during the review meeting because it assumes that the ARDVAC would only be used 3 hours per day due to traffic window constraints.
- Using a capital cost of $381,000, the ARDVAC would pay for itself after cleaning 3,124 miles under these assumptions.
- Assuming that the ARDVAC can clean 6 miles per day, using the ARDVAC instead of Caltrans employees will pay for itself in about 521 days of operation.
- The ARDVAC is more expensive than using probationers (although probationer costs vary greatly from district to district) or the Adopt-A-Highway scenarios.
- ARDVAC allows Caltrans to remove debris in areas where it has not been removed before.

Value to Caltrans Maintenance Workers: Increased Safety

- Reduced incidents of injuries because all workers will be inside vehicle.
- Reduced exposure to traffic
- Reduced injuries from manual litter pick-up (bending and lifting)

Value to Consumers: Reduced Roadside Debris

- Maintains natural beauty of surrounding environment.
- Reduces safety hazards for motorists.
- Reduces non-point source pollution in stormwater runoff.

Potential Yearly Market Opportunity: $15.8 million

There is a maximum need for 10 ARDVAC units within California and about 415 nationwide. This translates into a total statewide market of about $3.8 million and a total nationwide market of almost $158 million. Assuming that the ARDVAC has a useful life of 10 years, the yearly market potential is about $15.8 million. The assumptions underlying this analysis are:

- 10% of CA highway centerline miles could benefit from ARDVAC
- 7% of U.S. highway centerline miles could benefit from ARDVAC
- Each applicable highway mile would be cleaned with ARDVAC quarterly (every three months)
- Each ARDVAC can clean 1200 median miles in a year
- As indicated in the ARDVAC business review meeting, units would be used on roadways beyond those for which ARDVAC has been shown to be most applicable, leading to a greater demand in California than indicated here.

Technology

The technology integrates an easily-controlled, dexterous, end-effector with a commercial vacuum system. It is designed to be an add-on feature for existing, commercially-available sewer and ditch cleaning trucks. Using a joystick control from within a cab, an operator can quickly vacuum behind guard rails, down into depressions, and under bushes. The nozzle can be manually operated (likely by a user other than the driver), set in a single position or put in a raster scan mode in which it can scan a 4 foot wide path. ARDVAC tank capacity is 16 cubic yards. It was pointed out in the ARDVAC business case review meeting that the ARDVAC also can be used to quickly clear drains and even to pick up organic waste from landscaping activities.

Economic Model

Using the $122 per mile cost savings, an estimated 1200 miles per year cleaning capacity per ARDVAC and an estimated reduction in injury expenses, each ARDVAC can potentially save about $147,000 per year. This allows for a 2.6 year simple payback period of the $381,000 capital cost, or a 37% internal rate of return over its 10 year life.

Key Uncertainties/Unresolved Questions

- How correct are the assumptions underlying the main cost comparison?
- What is the actual pick-up rate of the ARDVAC?
- How much organic material is picked up with the litter (filling up the hopper and increasing dumping fees)?
- Exactly which road segments is the ARDVAC most useful for and what proportion of the highway system do these roads represent?
- Will Clean Earth be able to deliver the prototype units? Future units in production?
- Will the size of the ARDVAC (Class A driver's license requirement) limit its utilization rate?
- Will districts see the benefits of ARDVAC and choose to adopt it for picking up litter?

Next Steps / Recommendations

- Perform a detailed check of assumptions in this report
- Test pick-up capability on prototypes
- Perform a detailed study of applicability
- Use marketing and training to show the districts benefits of using ARDVAC
- Revoke patent license if Clean Earth fails to deliver prototypes
- Determine potential interest in ARDVAC from other state and local DOTs

Background

National Highway Litter Problem

Nationwide, the annual cost of roadside litter pick up was most recently approximated at $120 million in 1993[1] ($165 million in 2006 dollars). This figure does not include funds spent on advertising campaigns, education programs and law enforcement designed to deter motorists from littering.

In general, roadway and roadside litter costs taxpayers money, detracts from the natural beauty of the surrounding environment, creates safety hazards for motorists and can pollute nearby bodies of water through stormwater run-off.

Caltrans

Caltrans maintains 15,000 centerline miles and 49,000 lane-miles of highway. This includes over 12,000 bridges and over 230,000 right-of-way miles. The maintenance program organization within Caltrans is divided into 12 districts. Within each district, a Maintenance Support group is responsible for coordinating the equipment assignments, a Maintenance Engineering group is responsible for servicing the equipment, and the Deputy District Director of Maintenance (DDDM) allocates labor, expenditures, and equipment usage. The DDDM is also responsible for submitting the annual budget for his/her district, justifying any additions, upgrades/downgrades, or replacements. These equipment mix changes are also reflected by the Equipment Service Center in the Equipment Catalog. If equipment is not in the catalog or is not immediately available in the area, it can be rented from a third party. Purchases of new equipment must go through a competitive bidding process. The alternative, sole sourcing, makes the Caltrans internal purchasing process very time consuming. However, purchasing from multiple distributors is not considered sole sourcing.

The approval process for new equipment involves the Division of Maintenance and the Division of Equipment (DOE). These groups work together to determine what new equipment should be purchased. DOE develops the specifications and obtains approval through the Department of General Services. DOE then requests bids based on the specifications and makes the purchase.

The DDDM manages several Regional Maintenance Managers. Several Area Superintendents report to the Regional Managers. Below the Area Superintendents are several Maintenance Supervisors who are responsible for specific maintenance activities. Supervisors want equipment that helps them be more efficient and reduce worker exposure to traffic. Caltrans maintenance operations include activities such as paving, traffic safety, vegetation control and landscaping, snow removal, and crack sealing.

Caltrans as a whole has an annual budget of $8 billion, of which $393 million is appropriated for maintenance activities. In FY 04-05, Caltrans spent a total of $41 million on litter and debris removal[2]. This figure includes $13.4 million spent sweeping 185,000 lane miles of roadway and almost $18 million picking up 150,000 cubic yards of litter from the roadside using Caltrans, probationers, and Adopt-A-Highway forces.

Manual Litter Pickup

Manual litter removal involves crews of people walking the highway roadside, picking up individual pieces of litter with handheld litter picking devices and placing the litter into plastic bags. The bags are typically then collected in piles for Caltrans crews to pick-up later with a cargo truck or compactor. Sometimes a changeable message sign will be left near the bag piles to call passing motorists' attention to the amount of trash collected.

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[1] Andres, D.L. "Disposal of Roadside Litter Mixtures." National Cooperative Highway Research Program: Synthesis of Highway Practice 184, Washington, D.C., 1993

[2] Caltrans Terri Porter

There are three distinct groups who perform manual litter removal: Caltrans maintenance workers, Adopt-A-Highway participants and Special Programs Personnel (SPP) including probationers, inmates, California Conservation Corps and others.

Caltrans work methods and procedures are designed to minimize the amount of time workers spend on foot near moving traffic. There is a safety hierarchy when workers must be near traffic. The best alternative is protection inside a vehicle or piece of equipment, followed by physical protection while on foot (barrier vehicle, guardrail, other barrier) and the last choice is to have workers on foot without physical protection. With this hierarchy in mind, the median is often off limits and therefore litter pick-up is seldom performed in these areas. Many times crews will combine litter pick-up with other maintenance tasks such as landscaping. The frequency of dispatch for litter clean-up depends on the number of complaints about the area and the number of Caltrans resources available. Caltrans labor for litter removal accounts for about 25% of total labor.

Adopt-A-Highway groups are given safety training, safety equipment, bags and an encroachment permit and then are asked to pick-up trash on their adopted section of highway 6 to 52 times per year. They are not allowed to work in the median or cross traffic, and may perform other tasks such as vegetation removal, tree and shrub planting and graffiti removal. Crew sizes vary quite a bit, but average about 6 to 8 people.

SPP crews may include inmates or citizens sentenced to perform community service. Crew size may be up to 15 people, including a supervisor, such as a Sheriff's officer, that is paid by Caltrans. Equipment is often provided by Caltrans, including a van for transportation to the clean-up site and a portable toilet. Contracts to use SPP are negotiated at the District level. SPP labor is often in high demand because of its cost-effective nature. Unlike Adopt-A-Highway personnel, probationers are allowed to clean in the median if there is sufficient right-of-way, and physical protection and/or taffic control is provided for the safety of the workers when needed.

Sweepers

Sweepers are used to clean litter from the paved roadway. They are most often driven in a moving lane closure with a separate attenuator vehicle or with an attenuator attached directly to the sweeper. The attenuator serves to absorb the kinetic energy of an errant motorist to protect the sweeper driver from harm. A single driver can operate a sweeper anywhere between 10 and 14 miles per hour, depending on the amount of trash on the road. Typically a sweeper will completely clean 5 to 6 lane miles in a day.

There are basically three types of sweepers used by Caltrans: mechanical sweepers, vacuum sweepers and pull brooms. Mechanical sweepers have two brooms that push the debris to the center of the vehicle where another broom picks it up and places it in the hopper, while a vacuum sweeper uses a vacuum system to suck debris off of the pavement. Vacuum sweepers have different concerns than mechanical sweepers because they kick-up enough dust to cause air-quality concerns. Capital costs for these sweepers tend to be between $90,000 and $200,000, with a $100,000 premium for a compressed natural gas (CNG) engine. Some number of sweeper purchases is mandated by storm-water quality standards. Capacity is up to 4 cubic yards, although weight is more often a limiting factor than volume. Sweepers are capable of lifting their hopper to dump directly into a dumpster, which will then be emptied by a contracted waste management company.

Pull brooms simply push litter and debris off of the roadway into the shoulder or roadside. The broom can be angled either direction to push left or right of the vehicle. Brooms can be either self-propelled or trailer driven.

Table 1 shows a variety of sweepers and brooms listed in the Caltrans equipment catalog with Caltrans internal rental rates.

Table 1. Sweeper Caltrans Rental Rates

CT #	Description	Rental Rate	Power	Type
56504	Sweeper, Rotary, Self-Powered Broom, Gas, Towable	$11.62	Tow	Push
56507	Sweeper, Non-Pickup, Self-Powered	$17.59	Self	Push
56702	Sweeper, Yard, Self-Propelled, 48"	$23.09	Self	Push
56808	Sweeper, High Dump, 4 CY, Diesel	$78.18	Self	Pick-up
56811	Sweeper, High Dump, 4 CY, CNG	$111.54	Self	Pick-up

Barber Litter Picker

A Barber litter picker (http://www.hbarber.com/LitterCollection/LitterPicker/Default.aspx) is a towable piece of equipment that is capable of picking up larger pieces of debris than a sweeper. Sometimes the litter picker will lead a caravan including a sweeper and attenuator truck to pick up larger items, but statewide usage is very low. One worker is required to drive the tow truck. Picker capacity is about 1 cubic yard, although the collection bin cannot be lifted to dump debris into a dumpster. Caltrans operates the litter picker on the roadway and paved shoulders, although the machine was designed to operate on a landscaped area while being towed by a tractor.

Table 2 shows the Caltrans equipment catalog data for the Barber litter picker.

Table 2. Barber Litter Picker Caltrans Rental Rates

CT #	Description	Rental Rate
46238	Picker, Debris, Towable	$24.20

Caltrans Labor

The following are labor rate data for Caltrans workers used in IMMS reporting[3].

- Maintenance Worker: $27.58
- Caltrans Equipment Operator I: $32.26
- Caltrans Equipment Operator II: $34.61
- Caltrans Maintenance Supervisor: $41.74

Typically, a 15% to 20% overhead rate is applied to hourly labor costs. Using this data, an average hourly rate of $39.15 (including 15% overhead) was constructed.

Lane Closures

Maintenance must request lane closures from Traffic Operations, who has their own policies restricting lane closures due to traffic. Standard lane closures are 0.25 to 1.5 miles long. The out-of-pocket cost to Caltrans for an 8-hour lane closure is approximately $500. This includes putting down cones, servicing, and picking up cones. The lane closure requires a special vehicle and a crew of 2 to 3 maintenance workers[4]. It also often requires the employment of law enforcement officers. The total economic impact, including motorist delays, is approximately $5,000. In some cases, businesses have reported a drop in business of up to 90% due to closures.

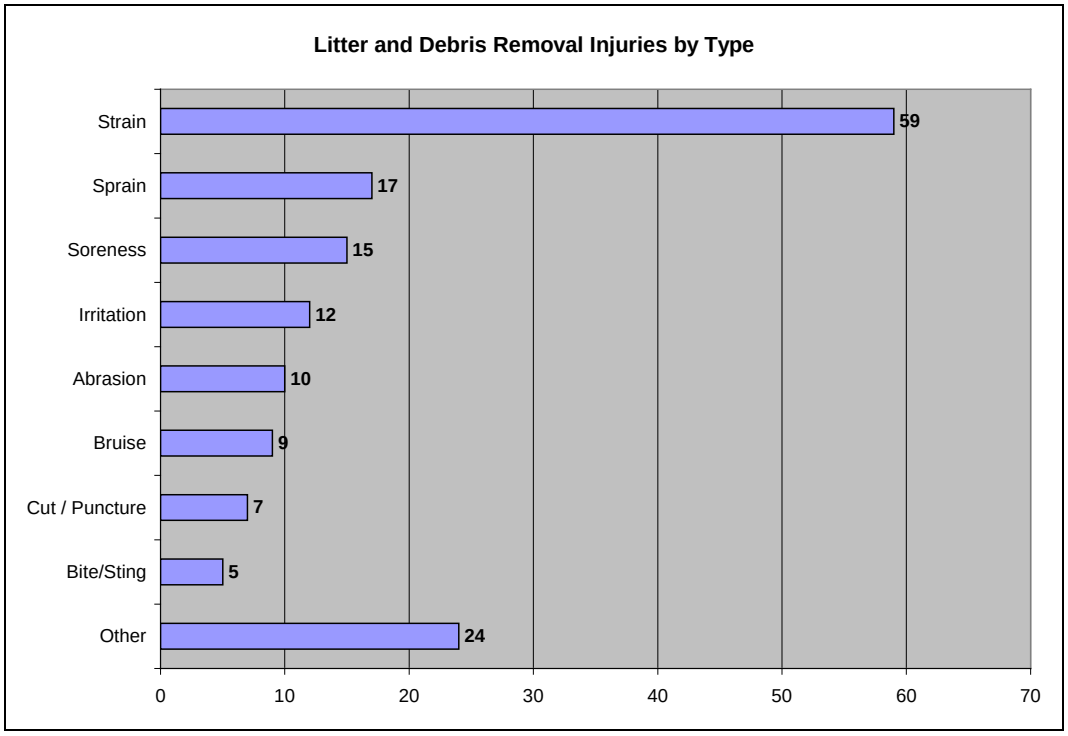
Injuries from Litter Pick-Up

Figure 1 shows the breakdown of injuries resulting from debris and carcass pick-up (Family D1) and litter pickup (Family D4) between 1/1/01 and 12/31/03[5]. The total number of injuries in this time period resulting from these activities was 158, costing Caltrans $887,000. Using this historical data, Caltrans can expect around 53 accidents per year costing a total of $296,000 in future years (average injury cost is

[3] Caltrans Courtney Morrison
[4] Caltrans Maintenance Manual Chapter 8.24
[5] Caltrans Wayne Wolf

about $5600 each). Any reduction in workers on foot required for litter pick-up can help reduce injuries and associated costs.

Figure 1. Litter and Debris Removal Injuries by Type (2001 through 2003)



Technology

Description

The ARDVAC integrates an easily-controlled, dexterous, end-effector with a commercial vacuum system[6]. It is designed to be an add-on feature for existing, commercially-available sewer and ditch cleaning trucks. The dexterity achieved with the ARDVAC system allows easy access to roadway edges and collection of the litter that tends to blow up against fence lines, vegetation and other objects. Using a joystick control from within a cab, an operator can quickly vacuum behind guard rails, down into depressions, and under bushes.

The boom that supports the ARDVAC nozzle can be moved to operate on the left or the right side of the vehicle, extended and raised up. The ARDVAC nozzle has a 12 inch internal diameter, which is larger than typical drain cleaning machines. While this feature allows ARDVAC to pick up larger objects, it also created some challenges in providing enough vacuum. The nozzle can be manually operated (likely by a user other than the driver), set in a single position or put in a raster scan mode in which it can scan a 4 foot wide path. ARDVAC tank capacity is 16 cubic yards, and the truck is large enough to require a class A license to operate. ARDVAC is wide enough that it may require a fixed lane closure to operate, especially if it cannot move along steadily in a moving closure.

While a vacuum truck meant for drain cleaning typically costs between $180,000 and $200,000, production cost for the entire ARDVAC unit is expected to be about $381,000.

[6] From AHMCT website

It was pointed out in the ARDVAC business case review meeting that the ARDVAC also can be used to quickly clear drains and even to pick up organic waste from landscaping activities, including cut grass and leaves.

Development Status

The ARDVAC project was started around 1998. A Vac-All drain cleaning truck was modified as a first working prototype, which had been evaluated as of June 2002. A field test under actual highway conditions was not feasible at this time, but testing was conducted along the AHMCT test road. At this time testing was conducted to see nozzle motion and debris removing capability as a variety of debris was spread along the roadway and then retrieved with ARDVAC. Video footage and still photographs were taken, but actual pick-up production capability was not determined.

Currently two full prototypes are being made by Clean Earth Technologies. There was some difficulty in creating the purchase order for these evaluation vehicles, as Clean Earth was the only source. The PO date was 4/13/05 and the prototypes are expected to be delivered to Districts 4 and 7 by August 2006. Prototype cost was $381,000 per vehicle, although there will be a discount because the order is late.

A follow on project has been started to look at the possibility of attaching cutters to the end of the nozzle to enable the ARDVAC to perform vegetation control operations as well as litter pick-up.

Visual Concept

Video is available at http://www.ahmct.ucdavis.edu/a_upvideo/dvac.mpg

Intellectual Property

The ARDVAC is protected under US patent number 6,789,291 B2 (9/14/2004) which is owned by the UC Regents. There is no international IP protection. The patent has been exclusively licensed to Clean Earth Technologies through 2011, although Caltrans is allowed to manufacture their own units. Field of use for the license is for a truck mounted industrial vacuum system with end effector for confined spaces. Since Caltrans funded the research that lead to ARDVAC, they have rights to a royalty free license in California, meaning that UC Davis does not receive revenue for sales to Caltrans but any sales made outside of California are subject to royalty fees.

If performance requirements are not met (sales goals, reporting requirements, license payments), then there is a possibility that UC Davis can reduce the license to non-exclusive or even revoke the license.

Markets

Market Analysis

Table 3 calculates the total market for ARDVAC inside California and for the United States as a whole. The size of the U.S. highway system under federal or state control is from the Bureau of Transportation Statistics[7]. Assuming that 10% of highway centerline miles in California and 7% of U.S. centerline miles could benefit from ARDVAC, total applicable centerline miles are calculated. California is assumed to have a greater proportion of applicable roads (divided highways, urban areas and guardrail). Each mile would be cleaned with ARDVAC every three months and there are two miles of median for each centerline mile of highway, which gives the total number of median miles cleaned. If each ARDVAC can clean 1200 median miles in a year (200 days of operation X 3 hours per day X 2 miles per hour), there is a need for 10 ARDVAC units within California and about 415 nationwide. This translates into a maximum statewide market of about $3.8 million and a nationwide market of almost $158 million.

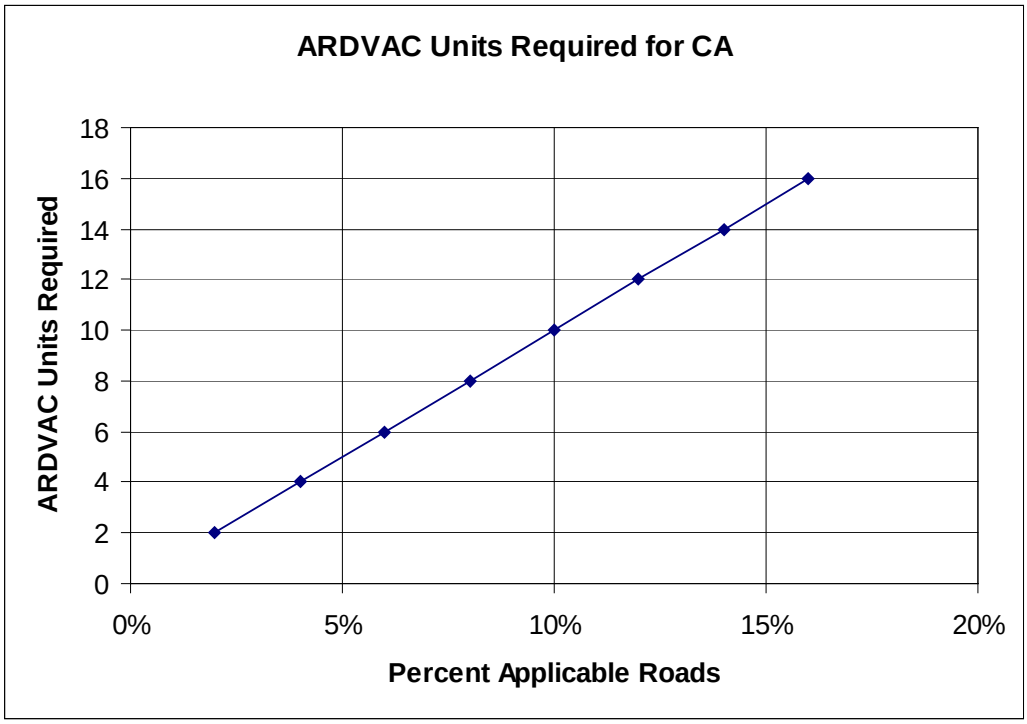
Table 3. ARDVAC Market Estimate – CA and U.S.

	California	U.S.	Units
Highway CL Miles Under State or Federal Control	15,000	890,175	CL Miles
% Where ARDVAC is Beneficial	10%	7%	Assumed
Total Applicable CL Miles	1,500	62,312	CL Miles
Cleanings per Year	4	4	Assumed
Total Median Miles Cleaned per Year	12,000	498,498	Median Miles / Year
ARDVAC Production Rate	1,200	1,200	Median Miles / Year
Total Potential ARDVAC Sales	10	415	Units
Cost per ARDVAC	$381,000	$381,000	$ / Unit
Total Potential Market	**$3,810,000**	**$158,273,115**	

The preceding analysis assumed that 10% of California's highway system would be suited for cleaning using ARDVAC, yielding a need for 10 units. Figure 2 shows how California's need varies with the proportion of applicable highways. As indicated in the ARDVAC business review meeting, units would be used on roadways beyond those for which ARDVAC has been shown to be most applicable, leading to a greater demand in California than indicated here.

[7] BTS Highway Profile,
http://www.bts.gov/publications/national_transportation_statistics/2002/html/table_highway_profile.html

Figure 2. Required ARDVAC Units vs. % Applicable Roads – CA



Manufacturers of Similar Equipment

Clean Earth Environmental Group, LLC
300 Fleming Road
Birmingham, AL 35217 USA
Telephone: (800)-382-8302
www.cleanearthllc.com

Profile
Over its 13-year history, Clean Earth has become a preeminent manufacturer of specialized sewer machines, street sweepers, and refuse trucks. Its growth has been fueled by its focus on value added machines; all of its products are highly customizable and focus on niche markets. The company's custom made trucks and technological innovations have allowed it to spread its scope across North America, as well as penetrate markets in many countries all across the globe. In February 2001, Clean Earth purchased the VacAll Division of Leach Company, adding a complimentary line of catch basins and street sweepers to the product line.

Products
The VacAll line from Clean Earth includes several models of vacuum street sweepers, catch basin cleaners and roadway debris vacuum systems. VacAll units remove wet or dry leaves and spills, clean sludge beds, sweep roadways and have hundreds of other uses.

Johnston Sweepers
Curtis Road
Dorking
Surrey
RH4 1XF, U.K.
Tel: +44 (0) 1306 884722
www.johnstonsweepers.com

Profile
Founded in 1904, Johnston Sweepers is the world's leading manufacturer of outdoor surface cleansing equipment.

Products
From shopping malls, city streets and pedestrian areas to new roads, building sites and major international airports, Johnston produces the most comprehensive range of roadsweepers and sweeping equipment for a diverse range of applications.

Madvac
Quebec, Canada
Telephone: (450)-616-8100
www.madvac.com

Profile
MADVAC International Inc. (formerly C.B.C. Municipal Equipment Inc.) offers a complete line of walk-behind, pedestrian-friendly sweepers and patented litter collection systems designed to eliminate the disadvantages associated with manual litter collection. Manual collection, which is costly and often inefficient, has become outmoded. The MADVAC vision is to promote the concept the litter collection, facilitate gains in employee productivity and create a positive image for your company and community.

Products
- Vacuum Litter Collectors – small self-propelled street sweepers and ground vacuum
- Portable Litter Collectors – portable vacuum units with hoses and nozzles to pick litter from fencelines and suck trash directly out of trash cans
- Compact Litter Collectors – litter collectors with overhanging hose that can be manually or robotically manipulated (no end effector)

Vac-Con
969 Hall Park Drive
Green Cove Springs, FL
Telephone: (904)-284-4200
www.vac-con.com

Products
- Sewer Cleaning
- Industrial Vacuuming
- Hydro-Excavation
- Sewer Flushing

Vactor
1621 S. Illinois Street
Streator, Illinois 61364
www.vactor.com

Profile
Vactor Manufacturing continues to be respected as an innovative designer and manufacturer of products using pneumatics. More than 6000 units have been sold worldwide, far more than any other sewer cleaner manufacturers.

Products
Combination Sewer Cleaners – sewer flushing and catch basin cleaning
Hydro-Excavator – using water to excavate soil
Jetters – scours sewer lines
Vaxjet – closed-loop surface cleaning system

Customer Value

ARDVAC Application

The first step in comparing the ARDVAC to current litter pick-up methods was to determine for which road characteristics the ARDVAC would provide the greatest benefits. Three attributes were selected with varying levels to determine the possible road characteristics:

- Location: median or roadside
- Shoulder: landscaped, paved or unpaved
- Barrier: Guardrail, No Barrier, Concrete or Transition (bridge support or ramp)

Looking at all possible combinations yields 24 different conditions. Since some can be eliminated because they are not feasible (unpaved shoulders with concrete barrier), only 16 were left for comparison. Each of three methods was qualitatively evaluated on a benefit / cost scale: ARDVAC, manual pick-up and a sweeper / Barber litter picker.

Figure 3 shows the application chart for the median. Here ARDVAC is most advantageously used to clean around guardrail and in transitions where debris tends to collect, but is not as useful in cleaning landscaped areas because it cannot go off the road and has a limited reach. Manual methods are very costly in the median due to safety concerns. Sweepers are best used with paved shoulders and a concrete barrier, where trash tends to collect up against the barrier. Sweepers are less effective at cleaning guardrail, transitions and areas with no barrier to collect trash.

Figure 3. Application Chart - Median

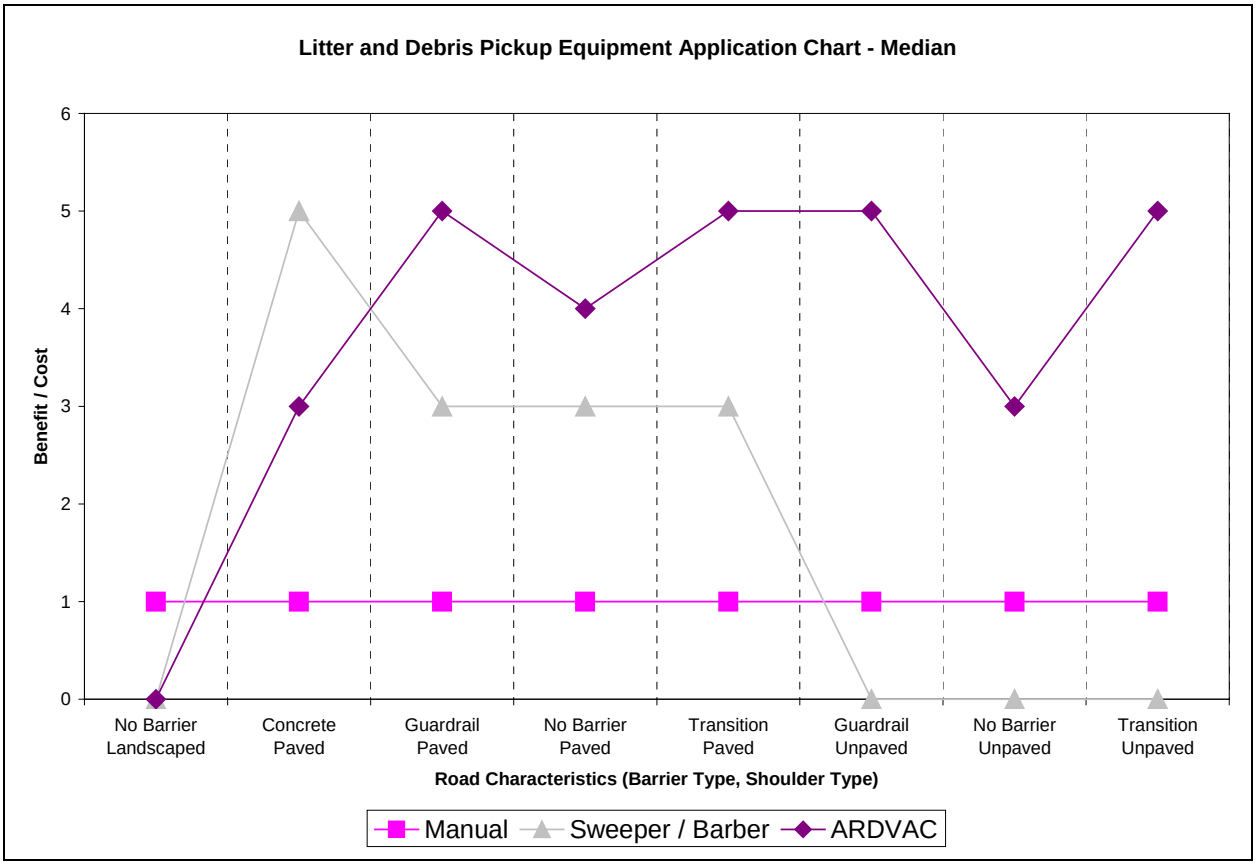
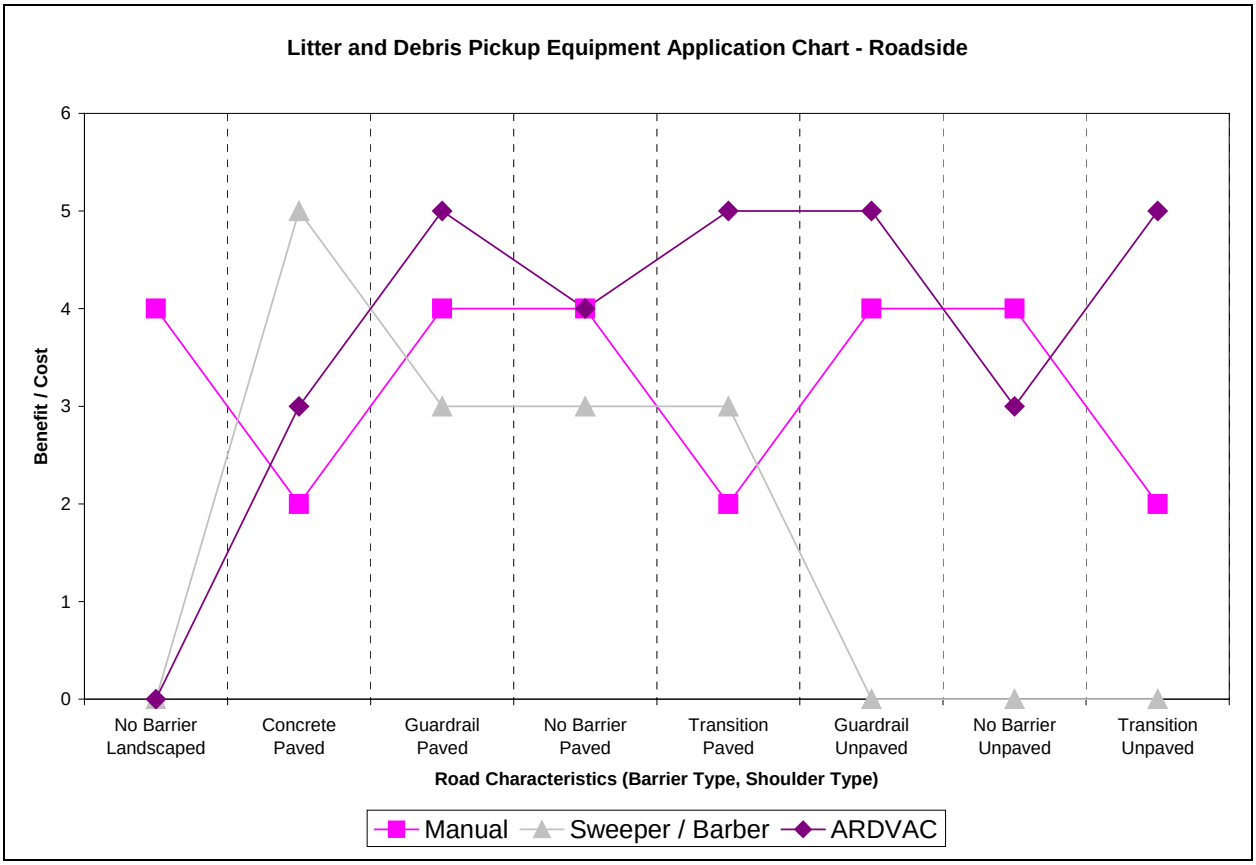


Figure 4 shows a similar chart for the roadside. In this case, the curves for ARDVAC and the sweeper are the same, but manual methods can be used. Manually methods are generally efficient except for

concrete barriers and transitions, where workers could be put in a compromising position with no way to safely avoid traffic. Here ARDVAC has a clear advantage cleaning transition areas that are often difficult to reach on foot and a small advantage cleaning around guardrail. Workers on foot can clean guardrail, but ARDVAC allows for improved safety.

Figure 4. Application Chart - Roadside



Cost Analysis

Figure 3 and Figure 4 and show that the ARDVAC has qualitative advantage over hand methods in a number of scenarios, namely in and around paved and unpaved guardrails and at transitions. In essence, the ARDVAC has potential value where clean-up by hand is currently being used or in locations where clean-up by hand could be used. Comparing the actual costs of the ARDVAC to existing hand clean-up methods, either by Caltrans employees, by probationers or by Adopt-A-Highway volunteers, can quantify the benefits of the ARDVAC and show where it is the most beneficial.

Assumptions

The quantification of the cost analysis includes eight different scenarios:

- ARDVAC with moving lane closure
- ARDVAC with fixed lane closure
- Hand clean-up by Caltrans employees with no lane closure (assumed large right-of-way)
- Hand clean-up by Caltrans employees with fixed lane closure
- Hand clean-up by probationers with no lane closure (assumed large right-of-way)
- Hand clean-up by probationers with fixed lane closure
- Hand clean-up by Adopt-A-Highway volunteers with no lane closure (assumed large right-of-way)
- Hand clean-up by Adopt-A-Highway volunteers with fixed lane closure

Note that not all eight of these scenarios are currently being used. For instance, Adopt-A-Highway volunteers are not allowed in the center median. The stats-quo for clean up in the median is to wait until road maintenance is required in the area and to then send in a crew to clean up debris. Also note that the ARDVAC would never be used in a no lane closure application; the reach of the arm is not long enough to allow for no lane closure.

The assumptions for crew size and equipment needs are given below in Table 4 and the assumptions for the cost rates are given in Table 5. Note that the ARDVAC, because it is not in Caltrans' possession does not have an actual rental rate. For this analysis, the assumed rate was $111.54/day, the same rate as "Sweeper, High Dump, 4 CY, CNG" (56811).

The source of the cost assumption is given in Table 5. The sources of the assumptions in Table 4 are primarily from discussions with Caltrans personnel and with members of the Advanced Highway Maintenance and Construction Technology (AHMCT) Research Center at UC Davis, the inventors of the ARDVAC. The production rate for the ARDVAC and for hand clean-up are from "2002-2003 Budget Change Proposal - Clean Up California Pilot Project" – September 13, 2001." Specifically, the report states: "If the ARDVAC can operate at a rate of cleaning two shoulder miles per hour, it will be ten times as efficient as the manual rate of one mile every five hours (this manual rate is an estimate that based on published industry estimates and needs to be confirmed by actual testing)." We interpreted the rate of 1.0 hand clean-up mile per five personnel equivalent to 0.2 miles per personnel and then multiplied this rate by the average number of personnel in the clean-up crew ("Number" in Table 4). "Number" for the ARDVAC is 1.0, because 1.0 ARDVAC's can clean-up 2.0 miles in one hour ("Miles per Hour" in Table 4).

The rates for dumping are highly variable based on the differing nature of each clean-up project. The rates in the table are considered averages and represent the typical amount of dumping per clean-up session.

A final note on the assumptions: the goal of establishing the assumptions is create a valid comparison between the ARDVAC and substitute cleaning methods. These assumptions represent the best estimates based on interviews with Caltrans personnel and in a variety of manuals.

Table 4. Table of Assumptions

Method	*ArdVAC*	*ArdVAC*	*Hand*	*Hand*	*Hand*	*Hand*	*Hand*	*Hand*
Lane Closure	*Moving*	*Fixed*	*None*	*Fixed*	*Fixed*	*None*	*Fixed*	*None*
Personnel	*Caltrans*	*Caltrans*	*Caltrans*	*Caltrans*	*Probationers*	*Probationers*	*Adopt*	*Adopt*
Clean-Up Labor								
CT Worker	2	2	2	2				
Hours/Laborer	5	3	5	3				
CT Supervisor					1	1		
Hours/Laborer					3	8		
Adopt-A-Highway							7	7
Hours/Laborer							3	7
Probationers					10	10		
Hours/Laborer					3	7		
Equipment								
ArdVAC	1	1						
Van (15 passenger)					1	1		
Big Truck			1	1				
Attenuation Truck	1							
Portable Toilet					1	1		
Dump Truck			1	1	1	1	1	1
Sign Board		1		1	1		1	
Cone Truck		1		1	1		1	
Closure Labor								
Set-Up								
CT Worker		3		3	3		3	
Hours/Laborer		1		1	1		1	
Maintenance								
CT Worker	1	1		1	1		1	
Hours/Laborer	5	3		3	3		3	
Close-Down								
CT Worker		3		3	3		3	
Hours/Laborer		1		1	1		1	
Dumping Labor								
CT Worker	1	1	1	1	1	1	1	1
Hours/Laborer	1	1	1	1	1	1	1	1
Production								
Miles per Hour	2	2	0.2	0.2	0.2	0.2	0.2	0.2
Hours	5	3	5	3	3	7	3	7
Number	1	1	2	2	10	10	7	7

Table 5. Table of Cost Assumptions

Labor

Name	*Rate*	*Units*	*ID*	*Full Name*	*Source/Notes*
CT Worker	$ 38.53	$/hr	0		Caltrans - Courtney Morrison
CT Supervisor	$ 48.00	$/hr	0		Caltrans - Courtney Morrison - 41.74*1.15 = 50.09
Adopt-A-Highway	$ -	$/hr	0		
Probationer	$ -	$/hr	0		

Equipment

Name	*Rate*	*Units*	*ID*	*Full Name*	*Source/Notes*
ArdVAC	$ 111.54	$/d	00000		Assumed rental rate - similar to Sweeper, High Dump, 4 CY, CNG (56811)
Van (15 passenger)	$ 17.19	$/d	00210	Van, Full Size, Maintenance, CNG	http://www.dot.ca.gov/hq/eqsc/rentalrates/RentalRateBook.pdf
Big Truck	$ 26.45	$/d	12330	UTILITY BODY 2.5TON 4WD DIESEL	http://www.dot.ca.gov/hq/eqsc/rentalrates/RentalRateBook.pdf
Attenuation Truck	$ 30.53	$/d	03349	Cargo Body, 15', Diesel	http://www.dot.ca.gov/hq/eqsc/rentalrates/RentalRateBook.pdf
Portable Toilet	$ 8.00	$/d	60101	Trailer, Portable Toilet, Cargo	http://www.dot.ca.gov/hq/eqsc/rentalrates/RentalRateBook.pdf
Dump Truck	$ 47.32	$/d	04920	Dump Body, 10 CY, Diesel	http://www.dot.ca.gov/hq/eqsc/rentalrates/RentalRateBook.pdf
Sign Board	$ 22.92	$/d	54816	Sign, CMS, 120", LED, Solar, Trailer Mtd	http://www.dot.ca.gov/hq/eqsc/rentalrates/RentalRateBook.pdf
Cone Truck	$ 20.45	$/d	01247	Utility Cone-Setter, Super 1-Ton, Gas	http://www.dot.ca.gov/hq/eqsc/rentalrates/RentalRateBook.pdf

Production Rates

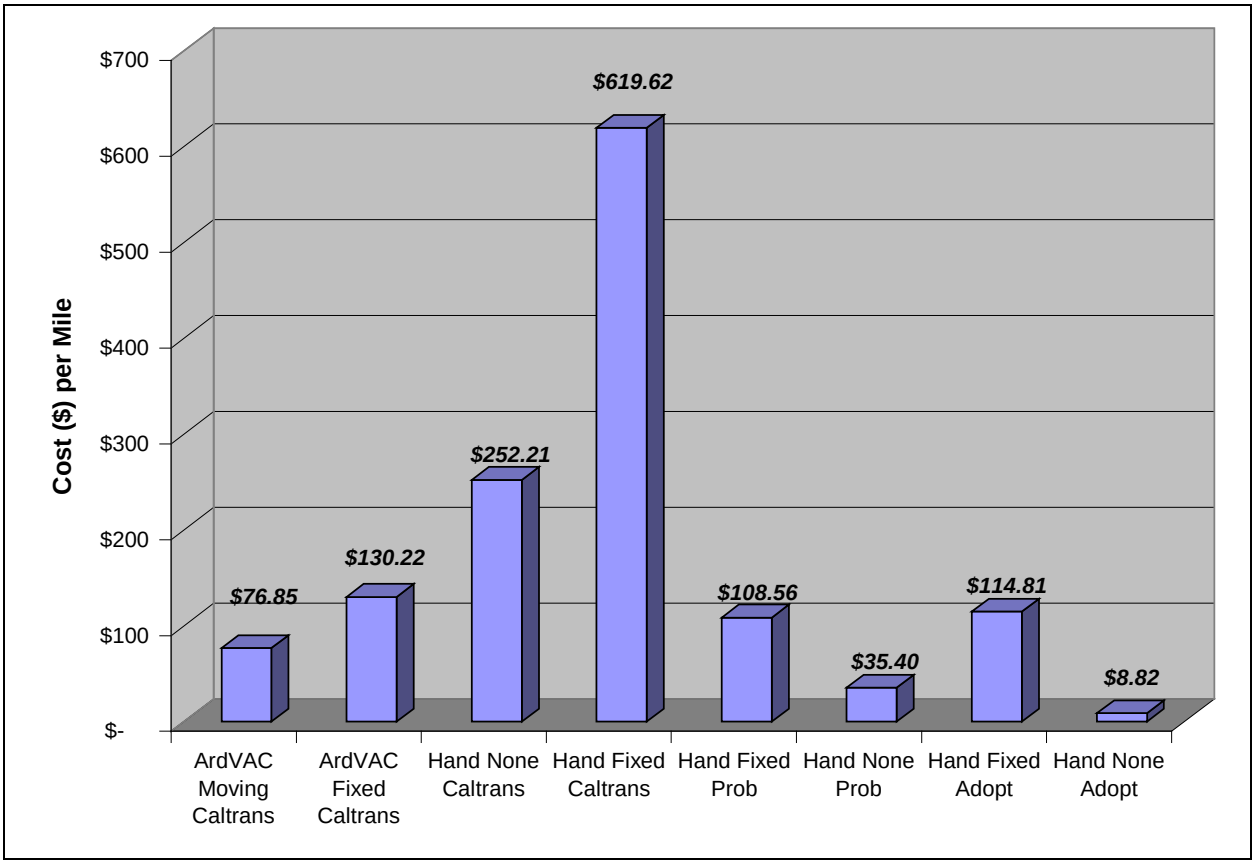
Name	*Rate*	*Units*	*ID*	*Full Name*	*Source/Notes*
Hand Cleanup	0.2	mi/hr/per	0		BCP#01122801zeroPYv4.pdf
ArdVAC	2	mi/hr	0		BCP#01122801zeroPYv4.pdf

ArdVAC price

Price	$ 381,000.00	$	0		From Caltrans

Using these assumptions, the total cost per day for each cleanup method was calculated and divided by the total production per day to give a comparable cost in units of dollars of debris clean-up per mile. A summary of these costs per mile is given below in Figure 5.

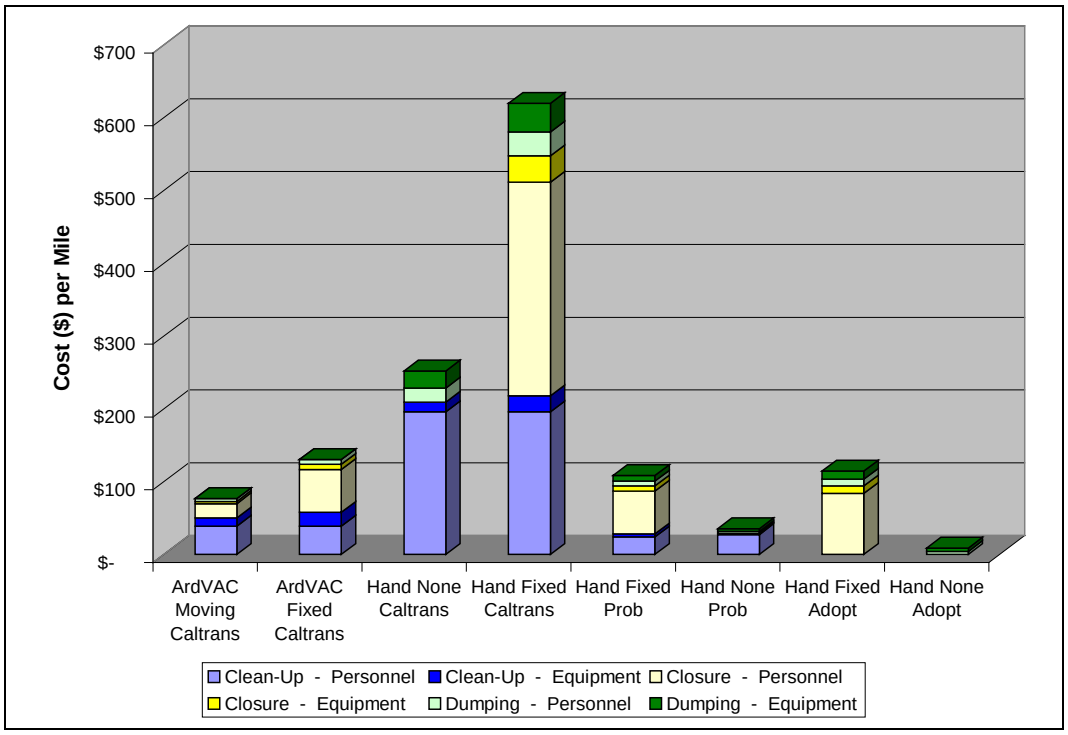
Figure 5. Cost per Mile of Debris Clean-Up



The cost per mile of debris removal using the ARDVAC with a moving lane closure is $76.85 per mile. For a fixed closure, the cost using the ARDVAC is $130.22, which compares favorably with the cost of sending a Caltrans crew out to clean up the same stretch of land, which is $252.21 (using a no lane closure). The ARDVAC is not cheaper than the probationer methods or the Adopt-A-Highway clean-up methods. However, the probationer cases are based on a statewide average estimate, and the actual probationer crew cost is highly variable from district to district. In some districts where demand for probationer crews is especially high, ARDVAC could still be more cost effective.

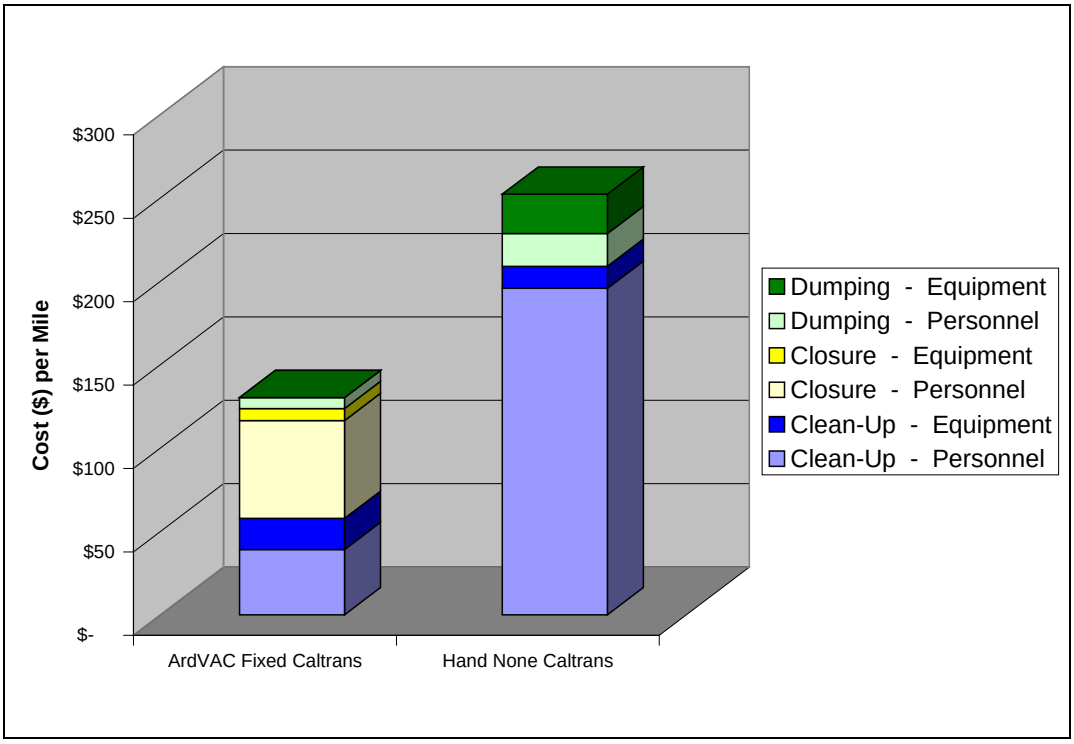
These costs can be broken down into costs of clean up, costs of lane closure and cost of dumping and each of these categories can be further broken down into personnel versus equipment costs and the results are shown in Figure 6. For the ARDVAC, the majority of costs are in Caltrans personnel for the operation of the ARDVAC and in the personnel costs associated with fixed or moving lane closure.

Figure 6. Cost per Mile of Debris Clean-Up Separated by Process



The same data are parsed to include a comparison of just the two most comparable scenarios and these results are presented in Figure 7.

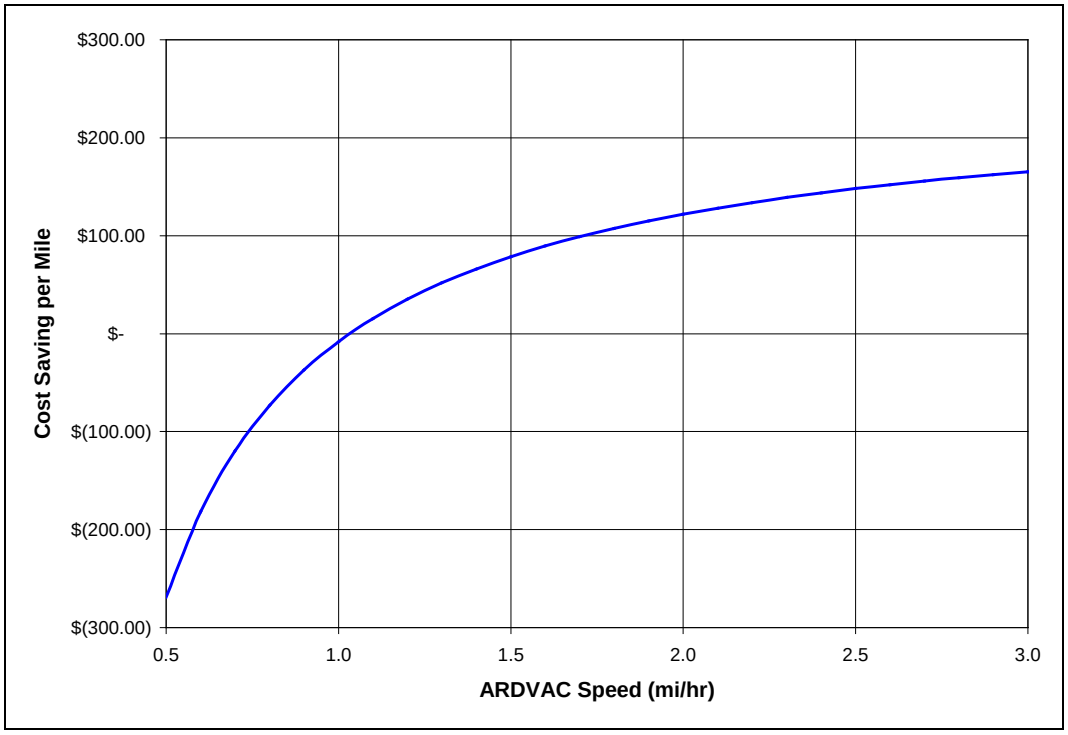
Figure 7. Cost per Mile of Debris Clean-Up Separated by Process for Fixed Lane Closure



As mentioned earlier, Caltrans does not currently use Adopt-A-Highway personnel in the medians with fixed lane closures. Thus, Figure 6 shows the cost comparison if Caltrans did decide to use hand clean-up methods in the median. In such a case, the ARDVAC is superior to using salaried Caltrans employees by $121.99 per mile. This value was identified as conservative during the review meeting because it assumes that the ARDVAC would only be used 3 hours per day due to traffic window constraints. Using a cost for the ARDVAC of $381,000, it would take 3,124 miles to for the ARDVAC to pay for itself under these assumptions. If, again using the assumption that the ARDVAC can clean 6 miles in one day, using the ARDVAC instead of Caltrans employees will pay for itself in about 521 days of operation. The ARDVAC is more expensive than using probationers or the Adopt-A-Highway scenarios.

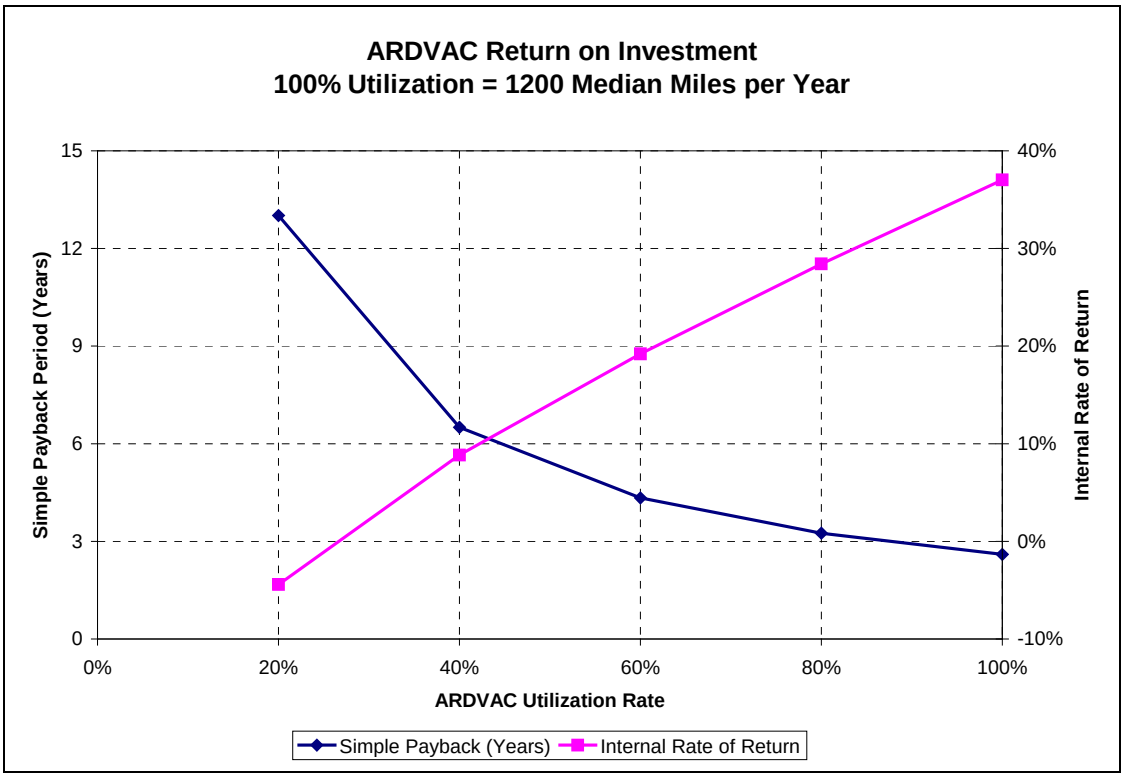
Figure 8 shows a sensitivity analysis of the cost savings using the ARDVAC versus by hand methods as a function of speed. At a speed of 2.0 mi/hr (the given assumption), the cost savings is $121.99. However, if the cleaning rate of the ARDVAC is slower than 2.0 mi/hr, the cost savings per mile decrease (assuming the by hand cleaning rate is constant). The ARDVAC is advantageous down to speeds of just over 1.0 mi/hr.

Figure 8. Cost Savings Per Mile vs. ARDVAC Speed



As shown in Figure 7, the most comparable cost savings scenario is ARDVAC with a fixed lane closure versus Caltrans manual pick-up without a lane closure, which yields a savings of about $120 per mile. Figure 9 shows return on investment for the $381,000 ARDVAC capital cost, assuming $120 cost savings per mile versus varying utilization rates. The max utilization rate is 1200 median miles per year for a single ARDVAC, which has a simple payback (capital cost / yearly savings) of 2.6 years corresponding to an internal rate of return (IRR) of 36%. Lower utilization rates yield longer payback periods and lower IRR values. A utilization rate as low as 45% (540 median miles) gives a payback period of about 6 years, with an acceptable IRR of about 10%. The total yearly cost savings also accounts for a projected decrease in injuries proportional to ARDVAC usage.

Figure 9. ARDVAC Return on Investment Chart



Benefits to Caltrans

Because of the high cost of Caltrans personnel time and because of the ARDVAC's improved efficiency in removing debris versus hand methods, the ARDVAC can lower operational costs for Caltrans. The savings is estimated at over $121.99 per mile. By reassigning these workers to other maintenance tasks, Caltrans can greatly reduce the backlog of work that has resulted from a staffing deficiency.

Benefits to Caltrans Maintenance Workers

Two Caltrans workers inside the ARDVAC cab operate the truck and one to operate an attenuator vehicle if using a moving lane closure. This will allow for few Caltrans personnel in the way of traffic which will reduce injuries.

Benefits to Caltrans Customers (Highway Users)

The primary benefit of the ARDVAC is that it will remove debris from locations from which it is infrequently removed currently. In general roadside litter costs taxpayers money, detracts from the natural beauty of the surrounding environment, creates safety hazards for motorists and can pollute nearby bodies of water through stromwater runoff.

Business Models

Current Business Model

Clean Earth Environmental Group has licensed the ARDVAC technology from UC Davis in order to finish the development for commercial application and then manufacture and sell units through their existing sales channels. The ARDVAC end-effector technology is a good complement to their existing VacAll business of street sweepers and sewer cleaning trucks. Unless Clean Earth begins to sell through multiple distributors, they may continue to have difficulty selling into government agencies such as Caltrans because of issues with being a sole source in a competitive bidding environment.

Alternative Business Models

Since Clean Earth owns an exclusive license to this technology in the United States until 2011, it is difficult to imagine alternative models to help commercialize ARDVAC. However, there may be several other options to start businesses around ARDVAC, such as rental or contracting.

A rental business model would involve buying ARDVACs from Clean Earth and renting them to various departments of transportation. The new enterprise would have to maintain, house and service the ARDVACs. The transportation agencies would still get the greater efficiency and economy of ARDVAC without having to make a large capital purchase. Rental could also help eliminate the issue that many government agencies have with sole source purchasing. The downside for Caltrans is that they would not own the equipment and would not always have ARDVAC immediately on hand.

Contracting would involve the new business buying ARDVAC from Clean Earth and providing litter removal services to transportation agencies. The business would need to house, maintain and service ARDVAC and learn the intricacies of litter removal. The DOT's would benefit by lower litter control costs for certain road segments resulting from ARDVAC's relative cost advantage.

Another possibility would be to license the technology under a different field of use, such as a stationary application for moving bulk materials. It may also be possible to manufacture and sell ARDVAC outside of the United States where there is no intellectual property protection (Madvac and Johnston Sweepers are both foreign companies). Of course this option would not provide any license revenue for UC Davis or AHMCT.

Key Uncertainties/Unresolved Questions

- How correct are the assumptions underlying the main cost comparison?
- What is the actual pick-up rate of the ARDVAC?
- How much organic material is picked up with the litter (filling up the hopper and increasing dumping fees)?
- Exactly which road segments is the ARDVAC most useful for and what proportion of the highway system do these roads represent?
- Will Clean Earth be able to deliver the prototype units? Future units in production?
- Will the size of the ARDVAC (Class A driver's license requirement) limit its utilization rate?
- Will districts see the benefits of ARDVAC and choose to adopt it for picking up litter?

Next Steps / Recommendations

- Perform a detailed check of assumptions in this report
- Test pick-up capability on prototypes
- Perform a detailed study of applicability
- Use marketing and training to show the districts benefits of using ARDVAC
- Revoke patent license if Clean Earth fails to deliver prototypes
- Determine potential interest in ARDVAC from other state and local DOTs

Business Case Review Meeting

An ARDVAC business case review meeting was held on June 5th, 2006 to go over the ARDVAC presentation and report. The main takeaway from the meeting was that many of the assumptions made for cost comparison, including the assumption that ARDVAC can only operate three hours per day in a fixed lane closure, are conservative. The decision was made not to alter the assumptions in this report since ARDVAC yields a significant cost savings and return on investment even under these conservative assumptions. Another key point brought up was that ARDVAC would be more applicable than indicated in this report. The units can be used for activities other than litter pick-up, such as quick drain cleaning and pick-up of landscaping waste. ARDVAC would also inevitably be used to clean road segments other than those indicated as most applicable in this report.

Meeting attendees were from Caltrans and the UC Davis Graduate School of Management:

Attendee	Organization
Eric Olson	UC Davis GSM
Lee Barton	Caltrans DRI
Bob Meline	Caltrans DRI
Todd LaCasse	Caltrans DRI
Nick Burmas	Caltrans DRI
Sheree Edwards	Caltrans Maintenance
Len Nelson	Caltrans Maintenance
Casey Skinner	Caltrans Maintenance

Related Publications

AHMCT Deployment Support Report – June 2002
www.ahmct.ucdavis.edu/projects/pdf/deploy_020630.pdf

ARDVAC Technology Profile
http://www.ahmct.ucdavis.edu/?pg=DebrisVacuum

References

AHMCT Website
http://www.ahmct.ucdavis.edu/

Caltrans Equipment Catalog
http://www.dot.ca.gov/hq/eqsc/EquipCatalog/

Caltrans Rental Rate Books
http://www.dot.ca.gov/hq/eqsc/rentalrates/RentalRate.htm

“2002-2003 Budget Change Proposal - Clean Up California Pilot Project - September 13, 2001”

Glossary of Terms

AHMCT – Advanced Highway Maintenance and Construction Technology Research Center at UC Davis
BCP – Budget Change Proposal, internal Caltrans document required to secure funding for projects that are outside of the normal budget.
Centerline Mile (CL) – Actual linear miles of roadway regardless of number of lanes
Lane Mile (LM) – Miles of roadway taking into account the number of lanes per centerline mile

Contacts

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Ed	Hardiman	Caltrans	Equipment		ed_hardiman@dot.ca.gov		Equipment / mtce costs
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Frank	Mele	Caltrans	Maintenance	Senior Transportation Engineer - Roadside	frank_mele@dot.ca.gov	(916) 651-6132	Stormwater issues
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Wayne	Wolfe	Caltrans			wayne_wolfe@dot.ca.gov		Injury costs
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Wil	White	UC Davis	AHMCT		wawhite@ucdavis.edu	(530) 752-1455	ARDVAC development
Andre	Chakovskoi	UC Davis	Technology and Innovation		chakhovs@ucdavis.edu	(530) 757-3430	ARDVAC IP / license
David	McGee	UC Davis	Technology and Innovation		drmcgee@ucdavis.edu		IP policy